Cosmos Multidisciplinary Research E-Journal
Online Available at www.cmrj.in
Recognized International Peer Reviewed Journal
Impact Factor 4.94
ISSN No. 2456-1665

The Impacts of Climate Change on Coral Reefs: A Review

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Abstract

Corals and coral reefs are immediate indicators of climate change. Over the past decade, we have observed a drastic change in the coral reef ecosystem due to various factors, primarily anthropogenic. One such factor is climate change, which has a direct effect on the reef ecosystem. Since pre-industrial times, anthropogenic carbon pollution has resulted in a 1°C increase in global surface temperature, making coral reefs sensitive and fragile. For the third consecutive year, coral reefs worldwide have experienced mass bleaching.

Keywords: *Coral bleaching, Thermal expansion, Coral mortality, Zooxanthellae.*

Introduction

Oceans cover 70 percent of the Earth's surface area and are home to 75 percent of all known species, making them the most productive environment on our planet. This largely unknown ecosystem regulates global temperature and produces substantial amounts of oxygen. Coral reefs are complex three-dimensional structures produced over thousands of years by reef-building coral species accumulating calcareous skeletons. They cover around 0.5 percent of the ocean floor and are known as the "Rainforest of the Sea." Coral reefs have a larger variety of animal and plant life than rainforests, distributing nutrients through a dynamic food web while providing food at all levels of the food chain. (1)

Historically, oceans have functioned as vital transit networks, sources of food, and popular leisure areas. Significant cities were built as business centres along the coast, and their expansion reflects their global population percentage. Approximately 80 percent of the world population lives within a hundred kilometres of the coast, relying on it for survival. The ocean's economic significance is demonstrated by the system services supplied by fishing, tourism, coastal protection, and raw materials. This dependency on the ocean is currently threatened by environmental conditions brought on by global climate change. (1)

Since pre-industrial times, anthropogenic carbon pollution has produced a 1°C increase in global surface temperature, resulting in catastrophic mass coral bleaching incidents. Changes in temperature leads to expel corals the zooxanthellae, residing in their tissues, responsible for their pigment. Bleaching can occur when ocean temperature increases by 1–2°C over

several weeks, turning corals white. Extended bleaching leads to coral mortality, often resulting in vast numbers of corals dying. Significant bleaching events have affected reefs worldwide, including the Great Barrier Reef in Australia, which bleached in 2016 and 2017, killing roughly half of its corals. (2)

As Earth undergoes phases where life flourished, withered, or suffered catastrophic reductions, change has been constant. Intrinsic events (e.g., volcanic activity) or extrinsic events (e.g., meteorite strikes) have occasionally led to hostile conditions, boosting extinction rates and causing ecosystem collapse. Compelling evidence now shows that human actions are causing rapid changes similar to those seen in the past. Many of these changes are already happening in the world's oceans, with major ramifications expected in the coming decades. (2)

Our understanding of how climate change affects marine ecosystems has lagged behind our understanding of its effects on terrestrial ecosystems due to the ocean's vast expanse and complexity, making measurements in marine habitats difficult. Long-term investigations of climate change in the oceans are rare compared to those on land. These developments highlight the urgency for the international community to act to limit atmospheric greenhouse gases and reduce substantial risks. (2)

Corals cannot withstand the current frequency of bleaching events caused by global warming. If temperatures continue to rise, bleaching occurrences will become more intense and frequent. Scientists suggest that even incidents occurring once every ten years can endanger corals' existence. Under a business-as-usual scenario, coral reefs in all 29 reef-containing World Heritage sites may cease to exist as functioning coral reef ecosystems by the end of the century. (24)

Rates of Change

Over the last 30 years, rising atmospheric greenhouse gas concentrations have raised global average temperatures by 0.2°C every decade, with the majority of this additional energy absorbed by the world's oceans. The heat content of the upper 700 m of the global ocean has increased significantly since 1975, with an average temperature increase of 0.6°C in the upper layers of the ocean over the last 100 years. Worldwide ocean surface temperatures in January 2010 were the second warmest on record for the month, with the six months from June to August 2009 being 0.58°C warmer than the 20th-century global average temperature of 16.4°C.

Anthropogenic CO_2 absorption has acidified the ocean's surface layers, with a constant loss of 0.02 pH units per decade over the last 30 years and a cumulative drop of 0.1 pH units since

pre-industrial times. Although these increases in pH appear minor, they are linked to a significant drop in carbonate ion concentrations, constituting a significant change from the geochemical conditions that have existed for hundreds of thousands, if not millions, of years. (2, 14, 15, 16)

Other changes have been triggered by increases in the ocean's heat content. Recent research confirms that ocean volume is likely to decrease due to growing stratification. Thermal expansion of the seas and increased meltwater from terrestrial glaciers and ice sheets have increased ocean volume. (3, 18) There is mounting evidence that diminishing oxygen concentrations played a key role in at least four or five mass extinction events, with deep-ocean anoxia releasing massive volumes of hydrogen sulphide into the atmosphere. (2, 18) These occurrences are linked to a higher risk of mass mortality among some deep-water benthic ecosystems, as seen recently along the west coasts of North America and southern Africa. The uneven distribution of energy also influences the behaviour of ocean currents, essential for the dynamics, local climates, and life of the ocean. (2)

The thermohaline or Meridional Overturning Circulation (MOC) is slowing due to disproportionate heating in Earth's polar regions, which has profound ramifications for regional climates. The MOC is most likely altering and will continue to change due to increased temperatures in polar regions and a drop in the salinity of surface waters due to ice sheet melt. (2, 19) Natural variability in the ocean climate system occurs on various time scales (seasonal to decadal), resulting in climatic phenomena including the El Niño–Southern Oscillation (ENSO), North Atlantic Oscillation (NAO), and Pacific Decadal Oscillation (PDO). (2, 22) Although our understanding of this variability remains uncertain, the steady increases in ocean and atmosphere heat content are likely to affect the strength, direction, and behaviour of the major current systems worldwide. (2, 19) Changes in ocean current behaviour can significantly impact the distribution and abundance of marine ecosystems, as evidenced by recent ENSO variability effects on kelp forests and coral reefs. (21)

Effects on Coral Reefs

A symbiotic interaction exists between corals and zooxanthellae, single-celled dinoflagellate algae. These microscopic algae reside within coral tissues, creating energy-rich chemicals through photosynthesis that the coral absorbs and uses as a food supply. Corals are highly dependent on this symbiotic relationship, obtaining up to 90% of their energy requirements from it. (7)

When the coral-algae interaction breaks down, bleaching occurs as a stress response. 'Bleaching' describes the loss of colour when zooxanthellae are evicted from coral hosts or their pigments are destroyed. The loss of zooxanthellae renders the tissue transparent, allowing the white of the calcium carbonate skeleton to shine through, giving the coral a bleached appearance. Foraminifera, sponges, anemones, and giant clams are among the species that bleach along with zooxanthellae. (7)

In some cases, coral bleaching causes corals to turn pastel shades of blue, yellow, or pink instead of dazzling white. Proteins generated by some corals colour the coral tissue and become the primary pigment during bleaching when zooxanthellae are absent. Increased water temperatures are the primary cause of coral bleaching. However, stressors such as disease, sedimentation, cyanide fishing, pollutants, and changes in salinity can also cause or aid corals in bleaching. (7)

Impacts of Climate Change on Coral Reefs

Bleaching: Corals are particularly sensitive to temperature variations. Rising water temperatures, linked to global warming, cause coral bleaching. When coral polyps are overwhelmed by heat or UV radiation, they eject the symbiotic algae within their tissues, leading to bleaching. The coral appears white or "bleached" once the algae are ejected. Corals derive the majority of their food and oxygen from these algae. While corals can recover after brief periods of bleaching, extended stress increases coral mortality. As sea temperatures rise, coral bleaching events and consequent reef death are predicted to become more common. (8, 10, 12)

Coral Growth: Sea levels are anticipated to rise by 6 to 37.5 inches (15 to 95 cm) over the next century. Coral's vertical growth rate is expected to be slower than this rise, causing corals to be deeper, receive less sunlight, and grow more slowly. Coastal areas will face issues due to deeper reefs and slower growth, including reduced reef sediment production, which helps build island land bases, and less coral protection for the shore, potentially increasing wave energy. (8, 10, 12)

Physical Damage: Increased storm and cyclone frequency and intensity are projected to cause higher coral mortality rates, as stronger waves and storm surges damage reefs more. Storm surge damage on coral reefs will be exacerbated by increased sea levels and a gradual reduction in storm water evaporation. More energy and time will be spent on reef repair, resulting in less time for new coral to grow. (8, 10, 12)

Mortality: The most serious effect of climate change is coral mortality. Coral reefs worldwide are experiencing mass mortality. The ultimate cause of reef degradation is mass coral mortality due to increased sea temperatures. Coral reefs may take decades to recover from climate change-induced coral bleaching and coral mortality events. [8, 10, 12]

The Role of Temperature and Light

Sea temperature rise is responsible for increased coral reef damage and mortality. Water temperatures in the Pacific Ocean have risen by 0.5–1.0°C since 1900, while those in the Indian Ocean have risen by 0.5°C since 1800. Coral reefs in shallow waters have a limited temperature range, typically between 23 and 29°C. In the tropics, most corals live in water between 23 and 29°C, with different species being more tolerant of temperature changes. Corals can adapt to water temperatures ranging from 18 to 33°C, depending on the circumstances. [23]

Conclusion

Immediate international action is required to conserve coral reefs and mitigate the impacts of climate change. While restoring coral reefs to their former state may be challenging, efforts must be made to preserve their existence and health. Coral reefs provide essential ecosystem services, and their decline will have significant economic, social, and environmental impacts. Future research should focus on understanding the adaptive mechanisms of corals less susceptible to bleaching, aiming to enhance the survival rates of remaining reefs.

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